Interaction of Volatiles, Sugars, and Acids on Perception of Tomato Aroma and Flavor Descriptors

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ABSTRACT: To better understand the effect of sugars and acid levels on perception of aroma volatiles, intensity of tomato earthy/medicinal/musty, green/grassy/viney, and fruity/floral aroma and flavor descriptors were evaluated using coarsely chopped partially deodorized tomato puree. This puree was spiked with 1.5% to 3% sugar (glucose/fructose combinations), 0.1% to 0.2% acid (citric/malic acid combinations), or water and 2 levels of 12 individual food-grade volatiles reported to contribute to tomato flavor. A panel consisting of 6 to 8 trained members rated 9 aroma, 8 taste, and 1 aftertaste descriptors of the spiked and nonspiked purees. The panelists detected significant differences ($P \leq 0.1$) for various individual aroma compound/sugar/acid combinations for a range of descriptors. Adding 0.2% acids alone to bland tomato puree decreased green and floral aromas as well as sweet taste. Adding 3% sugars alone increased green and musty aromas and decreased floral aroma as well as sour, citrus, and bitter tastes. Principal component analysis (PCA) explained 56.5% of the variation in the first 3 principal components (PCs) for added acids and volatiles to bland tomato puree. The effect of added acids with the various aroma compounds generally increased perception of overall and ripe tomato taste and aroma, tropical aroma, and sour taste, and decreased sweet, fruity, and bitter tastes. PCA for added sugars with volatiles explained 67.8% of the variation in first 3 PCs, and sugars generally decreased perception of sour, bitter, and citrus tastes and green aroma, while enhancing perception of flavors associated with ripe, tropical, and aromatic tomatoes. Adding sugars, acids, and volatiles together had a similar effect to addition of sugars alone.

Keywords: principal component analysis, sensory, tomato, volatiles

Introduction

Most tomatoes on the market today are bland in terms of aroma. Commercial tomatoes can generally be characterized by green, viney, earthy, and musty aroma, whereas very little fruity/floral notes are evident; volatiles of this nature are part of the tomato profile (Baldwin and Scott 2002). Thus, consumers are willing to pay a premium price for what they perceive to be premium quality, full-flavored tomatoes (Bruhn and others 1991; Neff 1996). Tomatoes have a characteristic sweet-sour flavor that is tempered by a complex mix of aromatic volatiles that interact with the sugars and acids present in the fruit (Petro-Turza 1987), both chemically and in terms of sensory perception. Some fruity/floral volatiles were found to enhance perception of sweetness, while other volatiles associated with green notes enhanced the perception of sourness (Baldwin and others 1998). Generally, studies have shown that sweeter tomatoes are more acceptable (Malundo and others 1995). March and others (2006) found that adding sugars and acids to kiwi fruit pulp affected panelists' perception of volatiles, partially due to interactions in the mouth, associated memories and release of some volatiles into the headspace. King and others (2007) reported that Brix and acidity can influence flavor profiles and accompanying odor intensity ratings for retronasal flavor descriptors by trained panels for beverages, but that flavor-driven gustatory sweetness enhancement seemed to be an effect only demonstrated by untrained consumers.

In a previous study, 2 major (often opposing) areas of tomato flavor were described (Baldwin and others 2004). From spiking of bland tomato puree with food-grade volatiles, reported to be important to tomato flavor, earthy-musty-viney-green aroma and the fruity- tropical-floral-ripe/sweet tomato aroma/tastes descriptors were reported by a trained panel. Principal component analysis (PCA) showed that similar portions of the variation were found for the 2 years of study (over 50%) and were due to these 2 broad areas of flavor, but that left a large part of the variation unexplained. This was assumed to be due, at least in part, to the contribution of sugars and acids and their effect on perception of sweet, sour, and bitter tomato tastes. In previous studies, it was demonstrated that liking of tomato flavor could be enhanced by varying the sugar and acid content (Malundo and others 1995; Brueckner and others 2007). In addition, sugars and acids have been shown to potentiate perception of aromatics in mango (Malundo and others 2001). This type of interaction is little understood and complicates sensory studies. Overall aroma perception as affected by sugars was partially addressed in another earlier study, where tomato puree spiked with sugars (Baldwin and Thompson 2000) was found to reduce overall aroma, ripe tomato aroma, and ripe tomato taste perception. The tomato aroma spiking study (Baldwin and others 2004) indicated that tomatoes high in green, viney, and musty notes

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(typical in the market now) could be altered for flavor through breeding or molecular transformation that selects for or upregulates, respectively, pathways that lead to volatiles contributing to fruity, floral aroma notes, which were found to be preferred in a consumer panel (Baldwin and Scott 2002). The interaction of sugars, acids, and volatiles, chemically and in terms of perception, was not considered in that study, but was the subject of this investigation, where volatiles were added to deodorized tomato puree, alone and in combination with added sugars and acids. The major sugars in ripe tomato are glucose and fructose while the major acids are citric and malic (Baldwin and others 1991); thus these sugars and acids were used for spiking of bland tomato puree. The objective was to see how the interaction of sugars, acids, and aroma volatiles influenced perception of tomato flavor and aroma.

Materials and Methods

Tomato puree

Local red-ripe tomatoes of unknown variety (150 fruits), purchased at a local supermarket in season, were refrigerated overnight at 5 °C, which generally reduces the level aroma compounds (Buttery and others 1987; Maul and others 2000), thought to be due to internal chilling injury. The fruit were then coarsely chopped in a Cuisinart (East Windsor, N.J., U.S.A.) with 10 pulses. The tomato puree was weighed out into 200-g portions and stored in plastic bags at –20 °C. One bag was thawed for each panel serving as the partially deodorized background ("Blank") into which the sugar, acid, and volatiles compounds were added. A subsample of puree was homogenized in a blender, then frozen for compositional analyses. The tomato puree was spiked with added sugar and/or acid levels or water. The stock sugar solution was 16% glucose/fructose (8% of each) and the base acid solution was 10% citric/malic, in equal amounts (5% of each), solubilized in deionized water. The volume of water, sugar, and/or acid solutions that were added to tomato puree samples was 37.5 mL of the sugar solution (18.75 mL of the lower level sugar solution plus 18.75 mL water or 37.5 mL of water alone) or 4 mL of the acid solution (2 mL of the lower level acid solution plus 2 mL water or 4 mL water alone). The levels that were added to tomato puree resulted in a total of 1.5% to 3% glucose/fructose (v/w) added to base sugar levels in the tomato puree (Baldwin and Thompson 2000) and 0.1% to 0.2% citric/malic acid. Thus, the sugar and/or acid spiked tomato puree contained a total of 3.67% and 4.42% total sugars (7.34 and 8.84 g total sugars, respectively, at the low and high levels) and 0.54% and 0.59% total acids (0.54 and 0.59g total acids, respectively, at the low and high levels). The individual volatiles were added to the partially deodorized puree with or without added sugars and acids at 2 levels (determined by a previous study, Baldwin and others [2004]) by pipetting under the surface of the puree (volatile concentrations added to puree are shown in Table 1). After sugars, acids, and/or volatiles were added, the puree was pulsed in the Cuisinart an additional 5 times (5 pulses) and immediately served to the panel. Volatiles were spiked individually (to bland puree with no sugar, acid, or water added) at level 1 except for 2-phenylethanol, which was spiked individually at level 2, and 3-methylbutanal and *cis*-3-hexenal, which were spiked individually at concentrations less than level 1 (1.35 and 4.8 μL/L, respectively) due to palatability and detection issues for the panelists. The panelists sampled 6 to 7 samples in a 4-h period.

Compositional analyses

Tomato volatile compounds were identified and quantified by gas chromatography (GC) as in a previous study (Baldwin and others 2004) using the headspace analysis technique described by Baldwin and others (1991, 1998, 2004) and Maul and others (2000), except without addition of calcium chloride, using a Perkin Elmer HS-6 headspace-sampler (Perkin Elmer, Norwalk, Conn., U.S.A.). The GC peaks for the aroma volatile compounds were quantified as microliters per liter using standard curves as determined by enrichment of bland tomato puree (Baldwin and others 1991, 2004). Not all volatile compounds used in the sensory test were detectable by this GC method. Samples of partially deodorized tomato puree with and without added high level of sugars (3%), acids (0.2%), or both sugars and acids (3% and 0.2%, respectively) and with or without 10 ppm of linalool, ethanol, or 6-methyl-5-hepten-2-one were analyzed by GC, as described previously, to determine if the maximum level of added sugars and acids would have an effect on volatile partitioning into the headspace.

Sensory

The samples (approximately 30 mL puree) were presented immediately after processing to a descriptive analysis panel (in 113 mL odorless plastic cups with lids) at room temperature. The panelists removed the lids, smelled, and tasted the puree (Baldwin

Table 1 — Volatiles added to puree with or without added sugars and acids (Baldwin and others 2004).

Volatiles added to puree	Conc (μL/L) (Levels 1 and 2)
Geranylacetone	2.0, 4.0
1-Penten-3-one	2.0, 4.0
Hexanal	2.0, 4.0
cis-3-Hexenal	7.2, 9.6
Acetaldehyde	15.0, 25.0
β-Ionone	1.0, 1.5
Linalool	2.0, 5.0
Ethanol	20.0, 30.0
2,5-Dimethyl-4-hydroxy-3 (2H) furanone (furaneol)	10.0, 15.00
2-Phenylethanol	2.0, 4.0
2 + 3-Methylbutanal	3.0, 6.0

Table 2 — Sensory descriptors generated for fresh tomato flavor[a] and standards used for training (Baldwin and others 2004).

Descriptor	Reference standards
Aroma	
Viney	Tomato vine and leaves
Green	Green beans (snapped open), green tomato
Ripe	Ripe tomato
Earthy	Wet dirt (mud)
Sweet tomato	Ketchup, tomato soup, V8, honey
Musty	Canned corn, feather duster, bird cage
Tropical	Mango, papaya, kiwi, guava
Floral	Scented flowers
Overall	Overall sensory experience of aroma (combined aromatics)
Taste	
Sweet	Sucrose solutions at 2%, 5%, 10%, 15% = 2, 5, 10, and 15 on line scale, respectively
Sour	Citric acid solution at 0.05%, 0.08%, 0.15% = 2, 5, and 10 on line scale, respectively
Ripe tomato	Cut ripe tomato, tomato puree
Tropical	Mango, papaya, kiwi, guava
Fruity	Apple, grape, apricot juice
Citrus	Lemons and orange juice
Bitter	Caffeine solution at 0.05%, and 0.08% = 2 and 5 on line scale, respectively
Overall aftertaste	General sensory aftertaste experience (combined aftertastes)

[a]Adapted from Meilgaard and others (1991) and Civille and Lyon (1996).

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and others 2004). A 15-cm unstructured line scale was used to evaluate the descriptors (Table 2). The panel consisted of 8 members who were trained using sucrose, citric acid, sodium chloride, and caffeine solutions to rate sweetness, sourness, saltiness, and bitterness, as well as with various materials for rating of aroma descriptors (Baldwin and Thompson 2000; Baldwin and others 2004) (Table 2). The panelists were trained for tomato evaluations in 14 two-hour sessions during which time they sampled the basic tastes (given to the panel every day for several weeks then once a week) described previously (sucrose, citric acid, sodium chloride, and caffeic acid) as well as various tomato products, fresh tomatoes (red-ripe and green), other fruit, and fruit products (Table 2). The panel was repeated for sugar and acid conditions with the volatile concentration at a higher level (Baldwin and others 2004).

Statistical analysis

The data are an average of panelists of 1 to 2 panels (panels were not repeated for both levels of volatiles). The data were transformed for each panelist by subtracting the panelist's average blank response. This allowed determination for each panelist if a treatment had a positive or negative effect on perception of descriptor intensity. The data, normalized for the blank, were analyzed with Statistica version 7 (Statsoft, Tulsa, Okla., U.S.A.) to perform an analysis of variance (ANOVA) test on the data. Homogeneous groups were determined using the Tukey unequal N honest significance test (HSD) at the $\alpha = 0.10$ level (Meilgaard and others 1991) for the high level of sugars and acids only (3% and 0.2%, respectively), but for both the high and low levels of volatiles. PCA was performed using treatment means across panelists (XLSTAT version 2007.1, Addinsoft, Paris, France). The results are presented as biplots of the first 3 principal components (PCs), where vectors indicate the contribution of each descriptor to each PC and sample scores are plotted in this multidimensional space for volatile level 1 only, but both the high and low levels of added sugars and acids.

Results and Discussion

The puree background

The refrigeration of tomatoes results in a puree that is in the below to low normal concentration range for acetaldehyde, acetone, 1-penten-3-one, hexanal, *cis*-3-hexenal, *trans*-2-hexenal, *trans*-2-heptenal, *cis*-3-hexenol, geranylacetone/β-damascenone (could not be separated), 2-phenylethannol, and β-ionone. Methanol, ethanol, 6-methyl-5-hepten-2-one, 2-isobutylthiazole, linalool, and p-nitro-phenylethane remain in the normal range (Baldwin and others 2004). Chilling tomatoes has previously been reported to result in reduced volatiles in fresh tomato fruit (Buttery and others 1987; Maul and others 2000). This method of partially deodorizing the puree (by refrigeration) was superior to the previously reported method of roto-evaporation (Tandon and others 2000) since the latter method generated a slight cooked odor. Chilling injury has been reported to result in membrane damage (Saltveit 2003), which may impair the lypoxygenase enzyme pathway resulting in C-6 aldehydes (hexanal, hexanol, *cis*-3-hexenal, *cis*-3-hexenol, *trans*-2-hexenal, and so on) from membrane lipids. Methanol, however, is constantly generated by action of pectinmethylesterase on

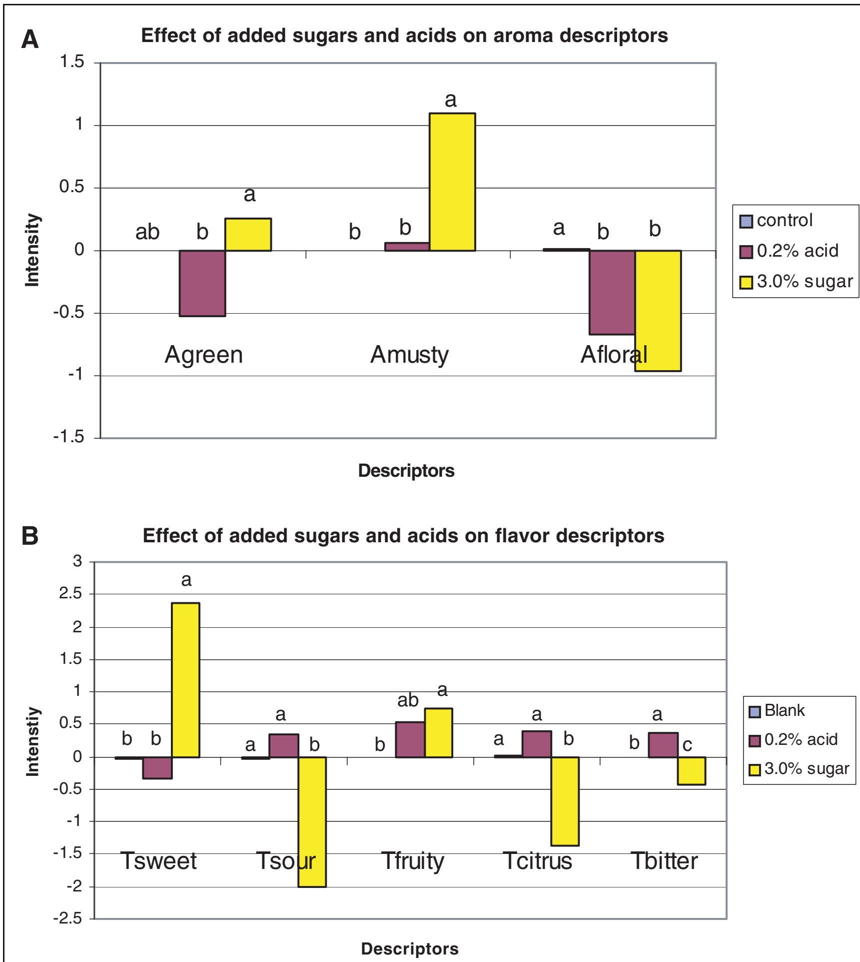

Figure 1 — Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with water (blank), a solution of 0.2% acid (equal amounts of citric and malic acids in water), or 3% sugars (equal amounts of glucose and fructose in water) (T = taste).

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methylated pectin (Baldwin and others 2000). Other enzyme systems that generate ethanol and acetone were not damaged by chilling temperatures (Baldwin and others 2004). Nevertheless, this chilling method resulted in a bland tomato background in which to study the effects of spiked tomato flavor compounds on sensory perception.

The effects of spiking sugars and acids alone at the higher level on flavor descriptors are shown in Figure 1 for those descriptors that showed significant differences. Aroma data are only shown for the higher levels of spiked sugars and acids for some of the spiked aroma compounds in Figure 2, and data for flavor (taste) in Figure 3 to 8, since these treatments resulted in the most significant differences. The PCA plots (Figure 9 to 11) include both the higher and lower spiked sugar and acid levels with all spiked aroma compounds.

Effect of sugar and acid spiking on flavor descriptor responses

Puree spiked with 3% sugar had more intense sweet and fruity flavors than puree spiked with acid (sweet flavor) or unspiked

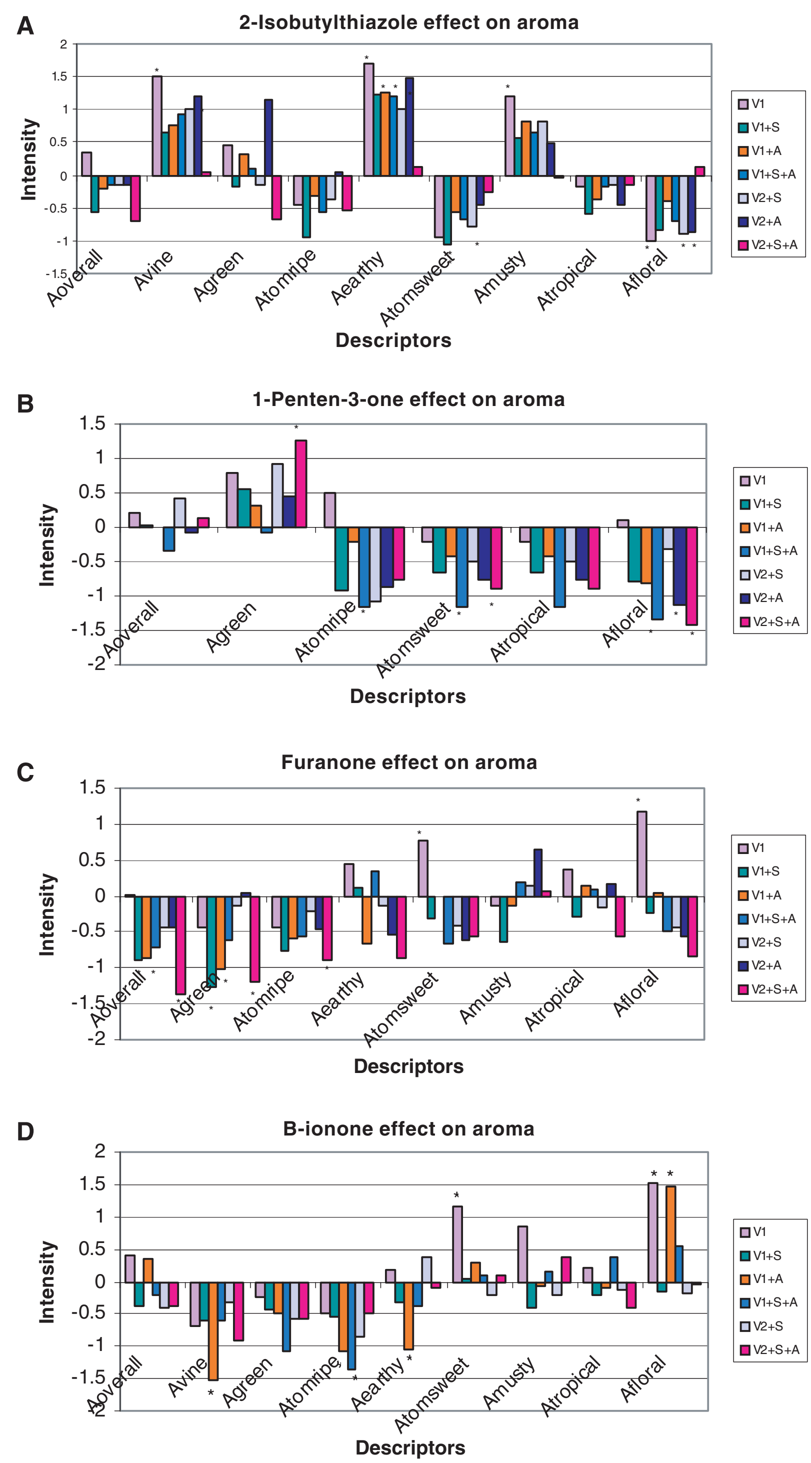

Figure 2—Aroma descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) 2-isobutylethiazole, (B) 1-penten-3-one, (C) furanone, and (D) β-ionone, and ± 0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (*) at $P \leq 0.1$.

puree, while the reverse was true for sour, citrus, and bitter flavors (Figure 1). For bitter flavor, puree spiked with 0.2% acid was rated higher for this descriptor than puree spiked with 3% sugar or unspiked control.

Effect of sugar and acid spiking in combination with earthy, green, or fruity volatiles on tomato aroma

The 12 aroma compounds tested were spiked into bland tomato puree alone or with various levels of sugars and acids at 2 levels. Of these, only a few are shown for aroma that had significant differences and are examples of the 3 types of flavor groups (earthy/musty/medicinal, green/viney/grassy, and fruity/floral; Baldwin and others 2004) spiked in combination with the higher sugar/acid levels. The treatments that were different from the unspiked control or blank (B) are marked with an asterisk (∗). 2-Isobutylthiazole, a volatile in the earthy/musty/medicinal category, which was described as having a pungent medicinal aroma in tomato puree (Baldwin and others 2004) and is unique to tomato (Baldwin and others 2000, Table 3), enhanced viney, earthy, and musty aromas, while generally decreasing perception of sweet tomato, tropical, and floral aromas (Figure 2A). 1-Penten-3-one is described as sweet, fruity, and grassy when added to tomato puree (Table 3). This volatile enhanced green aroma, but generally reduced perception of ripe tomato, sweet tomato, tropical, and floral aromas (Figure 2B). Furanone and β-ionone are described as having sweet, floral, and fruity aromas in tomato puree (Table 3). Addition of these volatiles decreased perception of the overall, green, viney, ripe tomato, and earthy aromas, while sometimes enhancing sweet tomato and floral aromas (Figure 2C and 2D, respectively). So the earthy/musty/viney/green volatiles detract from the fruity floral aromas and vice versa as was seen in a previous study (Baldwin and others 2004).

Effect of sugar/acid spiking in combination with earthy/musty/medicinal volatiles on tomato flavor (taste)

The unspiked "blank" (B) is shown to exhibit the panel variation and is sometimes so close to a zero value that it is not visible. In general, sugar-spiked samples were rated sweeter as well as less sour, bitter, and citrusy in flavor, regardless of the presence of volatiles, and so these aspects will not be further discussed.

Two volatiles of the earthy/musty/medicinal category (Baldwin and others 2004) were tested. Addition of 2-isobutylthiazole did not affect sweet flavor since all samples of puree with added sugar were rated sweeter than those without sugar or with added acid, regardless of whether the volatile was present or not (Figure 3A). Fruity flavor was decreased by adding the volatile alone (V1), but enhanced by added sugar and/or acid, with or without 2-isobutylthiazole. Citrus flavor was decreased by treatments that included sugar. Aftertaste was enhanced by 2-isobutylthiazole plus acid (V1 + A) and by level 2 of this volatile in combination with sugar plus acid (V2 + S + A).

2 + 3-Methylbutanal is described as nutty or stale in tomato puree (Table 3) and like bug spray, glue, or alcohol in aqueous or aqueous alcohol solutions (Tandon and others 2000). Addition of

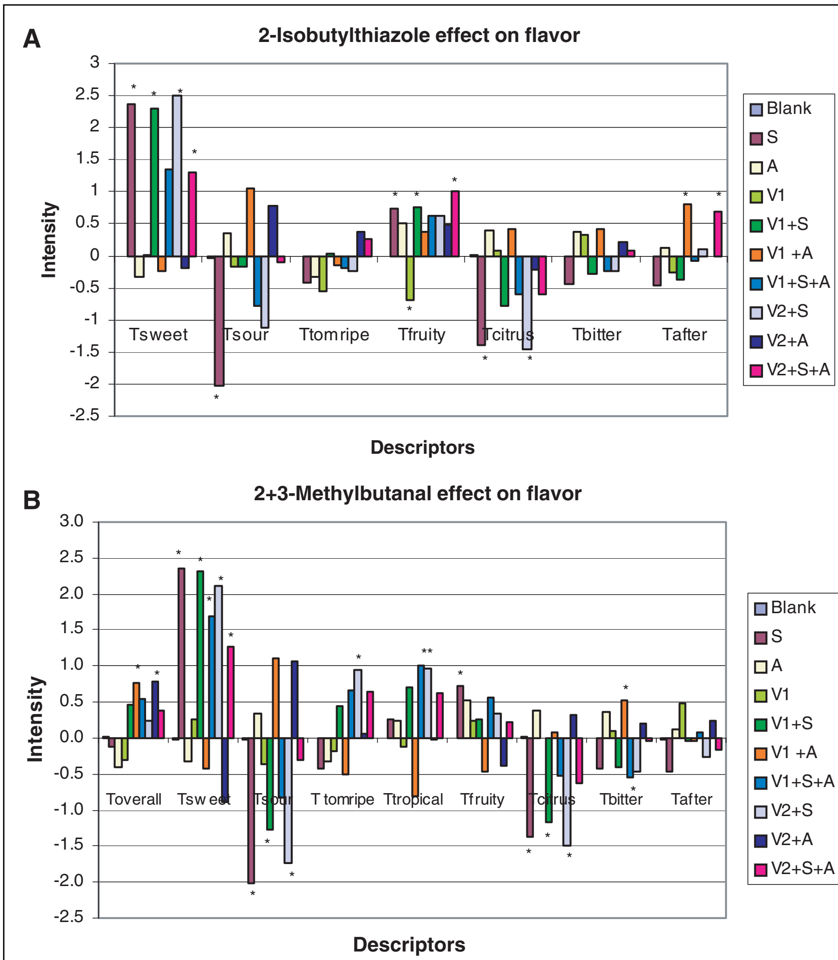

Figure 3—Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) 2-isobutylethiazole and (B) 2 + 3-methylbutanal, and ± 0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (*) at $P \leq 0.1$.

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2 + 3-methylbutanal did not affect sweet flavor since all samples of puree with added sugar were rated sweeter than those without sugar or with added acid, regardless of whether the volatile was present or not (Figure 3B). Overall, ripe tomato and tropical flavors were enhanced by the combination of 2 + 3-methylbutanal and either acid (overall flavor, V1 + A, V2 + A), the volatile plus sugar (ripe tomato, V2 + S), or volatile plus sugar and acid (tropical, V1 + S + A, V2 + S). Bitter flavor was enhanced by the lower level of this volatile with acid (V1 + A), but decreased when sugar was also added (V1 + S + A).

Effect of sugar/acid spiking in combination with green/grassy/viney volatiles on tomato flavor

Hexanal is described as having a green, grassy, or minty odor when added to tomato puree (Table 3). This combination level 2 hexanal plus sugar (V2 + S) decreased overall flavor, while the addition of hexanal did not affect sweet flavor since all samples of puree with added sugar were rated sweeter than those without sugar or with added acid, regardless whether the volatile was present or not (Figure 4A). Similarly for sour flavor, all samples with sugar decreased sourness: however, the higher level of this volatile with acid enhanced overall aftertaste (V2 + A).

cis-3-Hexenal is described as having a viney, green grassy, or tomato aroma in combination with tomato puree (Table 3). There was no clear effect of this volatile on sweet, sour, citrus, or bitter flavors, unless there was added sugar or acid (Figure 4B). The higher level of *cis*-3-hexenal also enhanced tropical and fruity flavors when combined with both sugar and acid (V2 + S + A) and bitter flavor when either level was combined with acid.

1-Penten-3-one is described as sweet, fruity, and grassy when added to tomato puree (Table 3). Addition of sugar generally contributed to differences in sweet and sour flavors, but addition of 1-penten-3-one enhanced the effect of added acid on citrus flavor as well as overall aftertaste (V1 + A, V2 + A) (Figure 5A).

Geranylacetone is described as sweet, citrus, and estery in tomato puree (Table 3). Addition of sugar generally enhanced sweetness and decreased sour, citrus, and bitter flavors as well as overall aftertaste, but this effect was compounded by geranylacetone (V1 + S, V2 + S) (Figure 5B).

Effect of sugar/acid spiking in combination with fruity/floral volatiles on tomato flavor

Furanone is described as having a sweet, floral, and fruity taste in tomato puree (Table 3). Added sugars and sugars plus acids were mostly responsible for effects on sweet, sour, and citrus flavor descriptors; however, this volatile alone enhanced perception of sweet taste without added sugar (Figure 6A).

β-Ionone is known for violet aroma and described as sweet and floral in tomato puree (Table 3). As with furanone, this volatile alone enhanced sweetness (V1) and, with addition of sugar, fruity flavor (V1 + S) (Figure 6B). β-Ionone decreased intensity of bitter flavor when combined with sugar, whereas sugar alone was not significantly different from the blank (V1 + S or V2 + S) (Figure 6B).

2-Phenylethanol is called the "rose" volatile, and was described as floral, fruity, and like roses in aqueous or aqueous alcohol solutions, but as alcoholic and nutty in tomato puree (Table 3). This

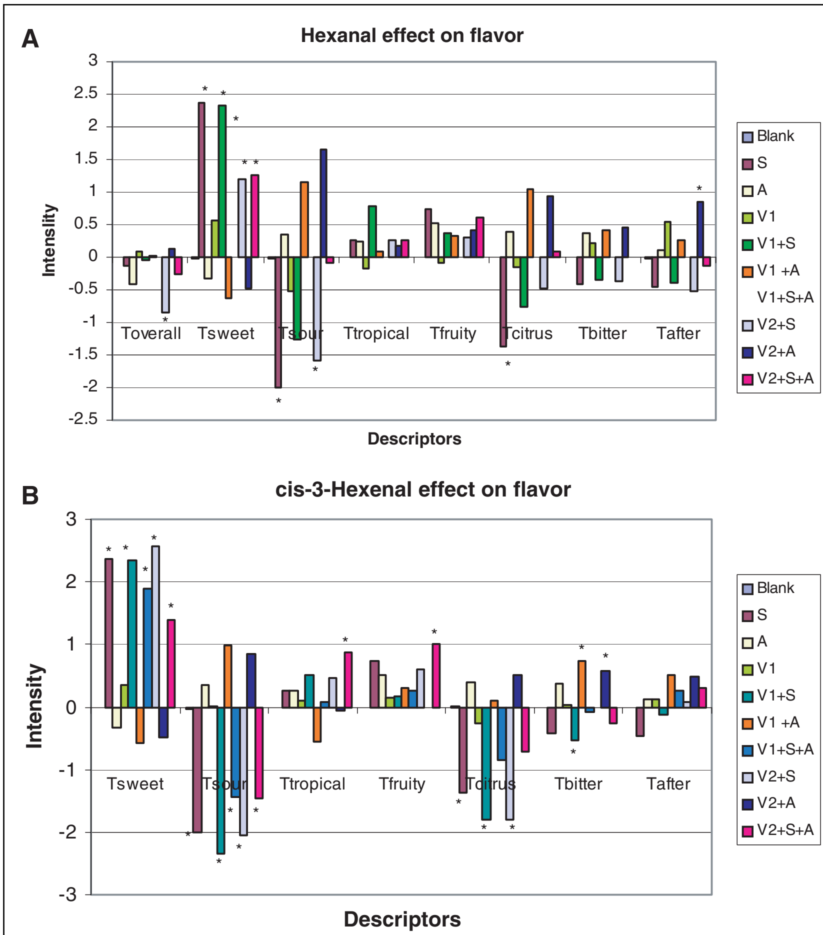

Figure 4 — Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) hexanal and (B) *cis*-3-hexenal, and ± 0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (*) at $P \leq 0.1$.

volatile enhanced tropical and fruity flavors when in combination with sugar or sugar plus acid, especially at the higher level (V2 + S and V2 + S + A), as well as overall aftertaste in combination with acid (V2 + A) (Figure 7A).

Linalool is described as having a citrus, fruity, and sweet aroma when added to tomato puree (Table 3). This volatile enhanced the overall (V2 + A), tropical (V1 + S + A), and fruity (V1 + S) flavors as well as bitter and overall aftertaste (V1+A) in combination with sugars and/or acids (Figure 7B).

Effect of sugar/acid spiking in combination with fermentative volatiles on tomato flavor

Acetaldehyde is described as sweet tomato, musty, tropical, and floral when added to tomato puree (Table 3). This volatile generally enhanced overall, ripe tomato (trend, not significant), tropical, fruity, and bitter flavors in combination with sugars and/or acids except for bitter flavor, where it was most effective alone at the lower level (V1) (Figure 8A). Acetaldehyde also detracted from sweet and enhanced sour flavor in combination with acids (V1 + A) more than added acids alone.

Ethanol is described as enhancing sweet taste in tomato puree (Table 3). This volatile enhanced overall flavor at both levels in combination with sugars and/or acids (V1 + S, V1 + A, V2 + S, V2 + A) and enhanced sour flavor in combination with acid more than acid alone (V1 + A, V2 + A) (Figure 8B). Ethanol enhanced ripe tomato and tropical flavors in combination with sugars or sugars and acids (V1 + S, V1 + S + A, V2 + S) and citrus flavor at the higher level with acids (V2 + A). It also detracted from bitter flavor in combination with sugars or sugars plus acids (V1 + S, V1 + S + A, V2 + S, Figure 8B).

PCA for added sugars

With so many changes in descriptors due to added volatiles, sugars, and/or acids at different levels, it is difficult to get a comprehensive picture. PCA is helpful in this case to map out general trends. The PCA of data resulting from addition of sugars (at 1.5% and 3%, 1S and 2S, respectively) without acids to the spiked puree shows that 54% of the variance is explained by the first 2 PCs (F1 and F2), and the 3rd PC (F3) explains an additional 14% of the variation (Figure 9A and 9B) for a total of 68%. All the spiked samples without any sugar added, except furanone (F-0) and β-ionone (B-0), and the unspiked puree control (blank, blk), were far in the left quadrant (very negative scores on PC1), characterized by taste descriptors such as bitter, citrus, and sour, as well as musty aroma (Figure 9A). When sugars were added without volatiles (sug), the puree was perceived as more sweet and fruity. Samples spiked with sugar as well as acetaldehyde, ethanol, linalool, 2 + 3-methylbutanal, or 1-penten-3-one had high positive scores on PC1 (A-1S, A-2S, E-1S, E-2S, L-1S, L-2S, P-1S, P-2S), with aroma and taste descriptors such as ripe tomato, tropical, and overall taste and aroma, and sweet tomato aroma. The higher level of added sugar resulted in even higher scores on PC1. In other words, addition of sugars

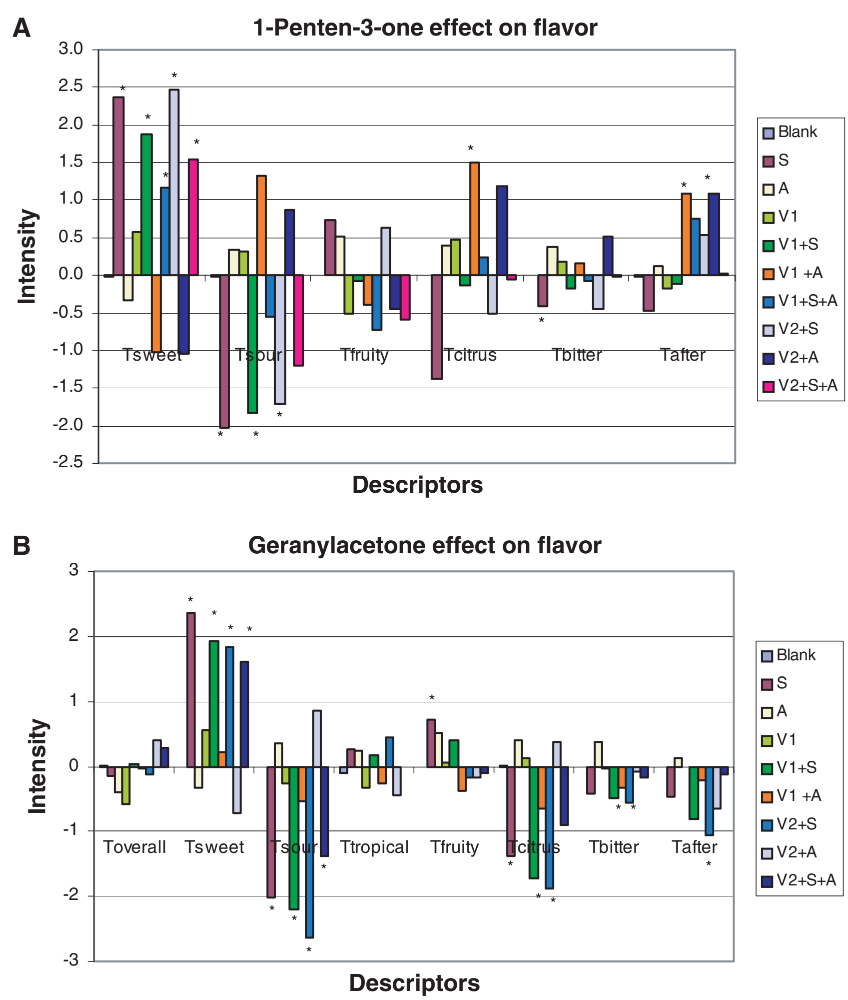

Figure 5—Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) 1-penten-2-one and (B) geranylacetone, and ± 0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (∗) at *P* ≤ 0.1.

to tomato puree spiked with these volatiles decreased the perception of sourness, bitterness, and citrus flavor, while enhancing perception of flavors associated with ripe, tropical, and aromatic tomatoes.

Adding sugar to samples spiked with *cis*-3-hexenal, hexanal, 2-phenylethanol, and 2-isobutylthiazole decreased the sample scores on PC2, thus characterized as having less bitter, citrus, and sour taste as well as earthy and musty aroma. These samples also had increasing scores on PC1 with added sugar (C-0, C-1S, C-2S, H-0, H-1S, H-2S, O-0, O-1S, O-2S, I-0, I-1S, I-2S). Adding sugar to samples spiked with geranylacetone and β-ionone resulted in lower scores on PC2 and higher scores on PC1 with descriptors of sweet and fruity taste (G-0, G-1S, G-2S, B-0, B-1S, B-2S).

The 3rd PC gives additional information on floral and sweet tomato aromas (positive on PC3), and on musty, earthy, viney, and green aromas (negative on PC3) (Figure 9B). Samples spiked with β-ionone and furanone had high positive scores on PC3 (B-0, F-0), and samples spiked with 2-isobutylthiazole had very negative scores on PC3 (I-0). While adding sugar to samples spiked with β-ionone and furanone decreased the intensity for floral and sweet tomato aromas (B-1S, B-2S, F-1S. F-2S), adding sugar to samples spiked with 2- isobutylthiazole did not modify the perceived intensity of musty, earthy, or viney aromas (I-1S, I-2S).

PCA for added acids

The PCA results for data from addition of citric and malic acids (0.1% and 0.2%, 1A and 2A, respectively) to puree spiked with volatile compounds show 45% of the variation explained by the first 2 PCs, and an additional 12% is explained by PC3 for a total of 57%. Adding acid without volatiles (acid) moved the blank (Blk) from floral/fruity toward bitter on PC2. Samples spiked with acid and linalool, 1-penten-3-one, or ethanol went from very negative scores (L-0, P-0, E-0) on PC1 (sweet taste) to high positive scores (L-1A, L-2A, P-1A, P-2A, E-1A, E-2A) on PC1 toward overall, ripe tomato taste and aroma, tropical aroma, and sour taste (Figure 10A). Acetaldehyde, 2 + 3-methylbutanal, and geranylacetone had similar changes on PC1 after addition of acids.

Adding acids to samples spiked with furanone decreased PC2 scores (F-0, F-1A, F-2A), characterized by floral and sweet tomato aromas on the positive side, and musty, green, viney, earthy aromas and citrus and bitter taste on the negative side (Figure 10A). Adding a high level of acids to samples spiked with β-ionone did not change scores much on PC1 or PC2, yet they remained in the upper left of the biplot quadrant (Figure 10A). Added acids did not change scores for samples spiked with hexanal, *cis*-3-hexenal, or geranylacetone.

Adding acids to samples spiked with 2-isobutylthiazole (I-0), initially with a very negative PC2 score (green, viney, earthy, and musty

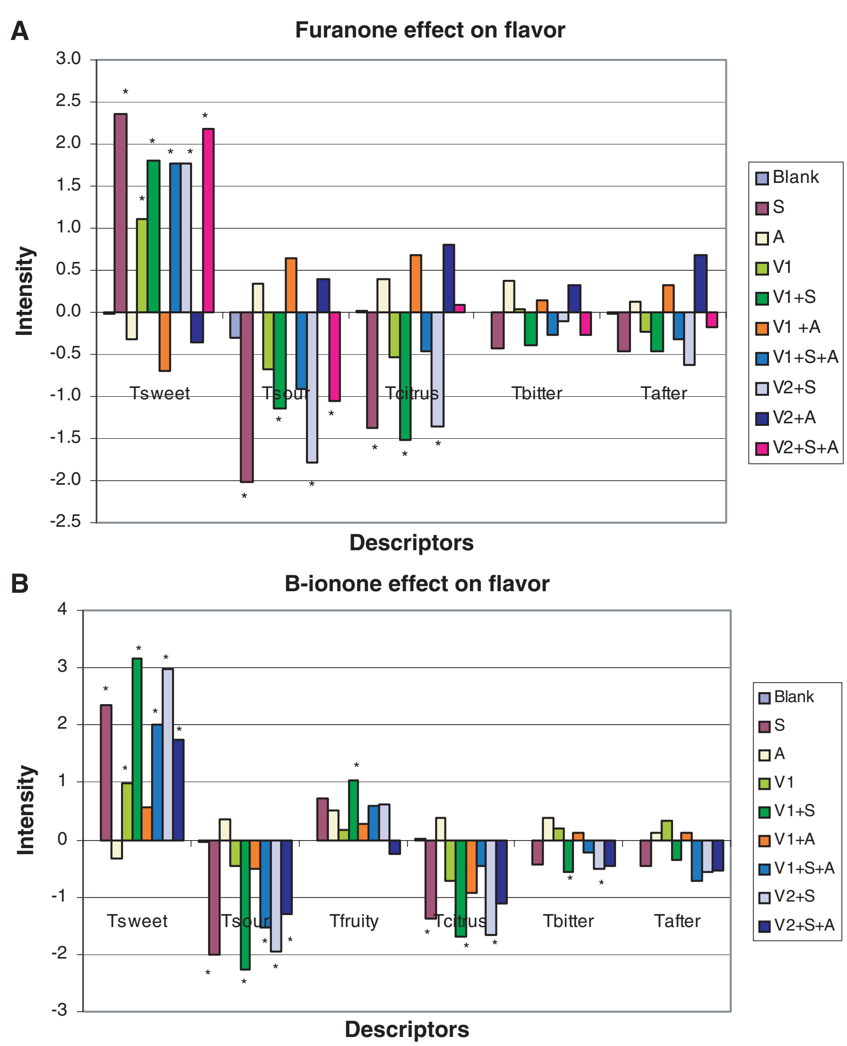

Figure 6—Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) furanone and (B) β-ionone, and ± 0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (*) at $P \leq 0.1$.

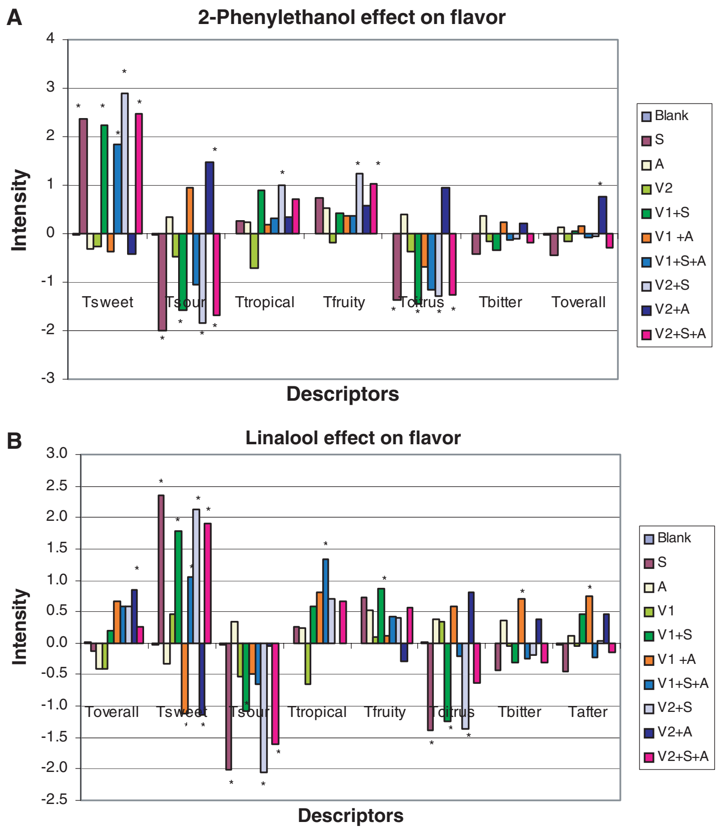

Figure 7—Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) 2-phenylethanol and (B) linalool, and ±0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (*) at *P* ≤ 0.1.

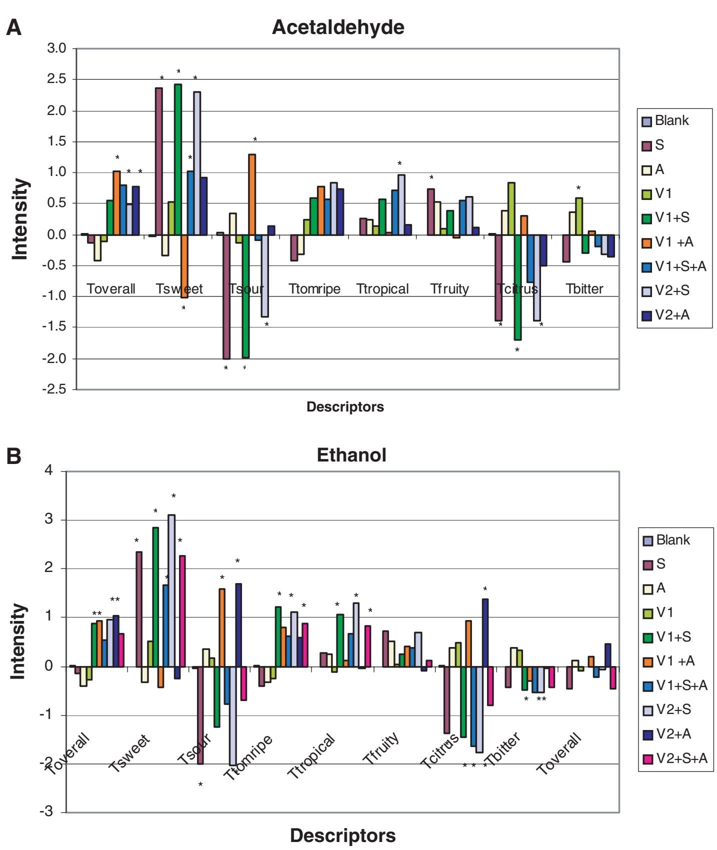

Figure 8—Flavor descriptor intensities (difference from unspiked blank) for deodorized tomato puree spiked with the volatile (A) acetaldehyde and (B) ethanol, and ±0.2% acid and/or 3% sugar solutions. Sugar = S, acid = A, V1 = volatile alone, volatile level 1 + sugar = V1 + S, volatile level 1 + acid = V1 + A, volatile level 1 + sugar + acid = V1 + S + A, volatile level 2 + sugar = V2 + S, volatile level 2 + acid = V2 + A, volatile level 2 + sugar + acid = V2 + S + A. Significant difference from control or blank (B) is designated with an asterisk (*) at *P* ≤ 0.1.

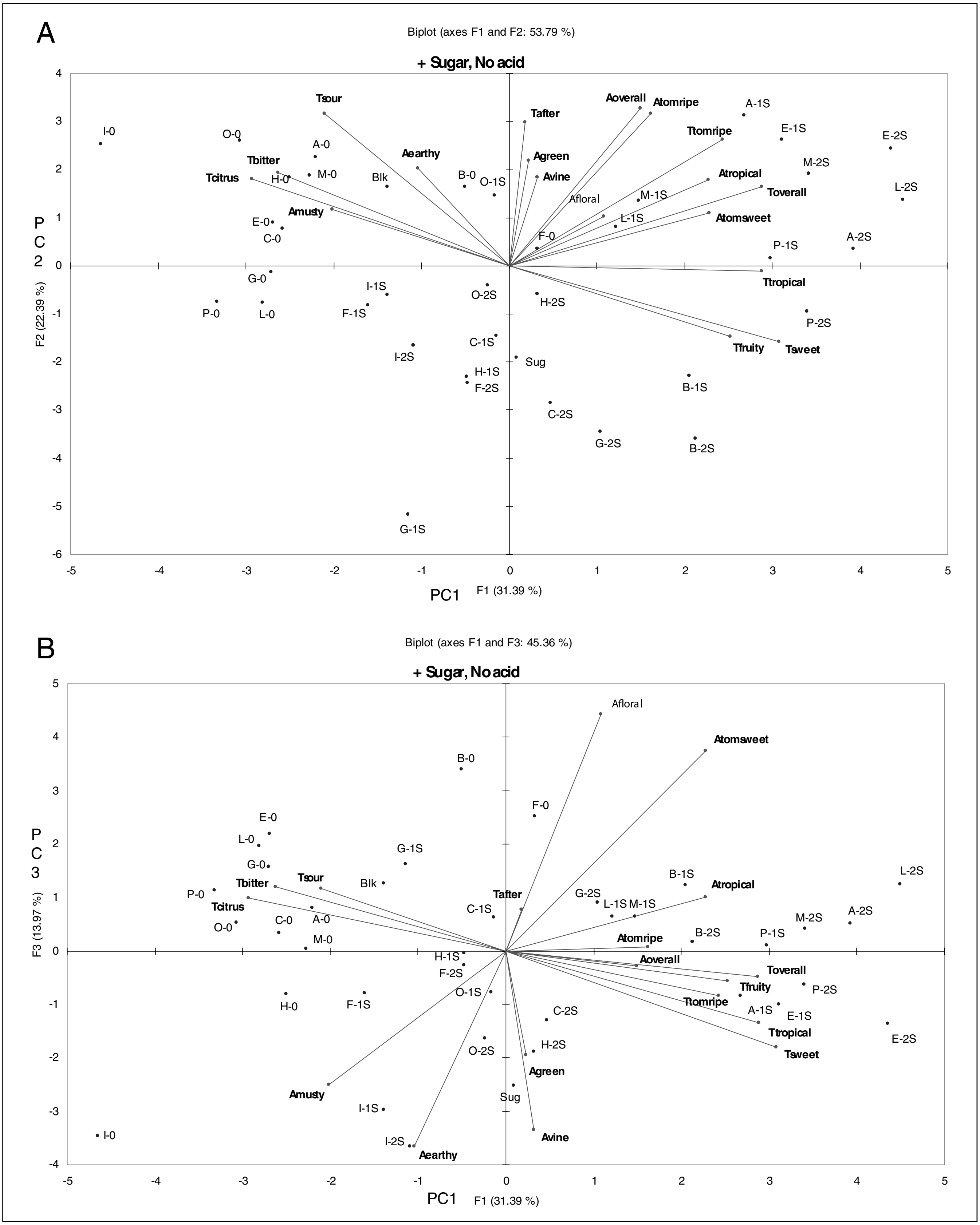

Figure 9—PCA of taste (T) and aroma (A) descriptors from tomato puree spiked with 1.5% or 3% sugar solutions in water (1S and 2S, respectively) compared to unspiked puree or blank (Blk) spiked with sugar alone (sug), geranylacetone (G), 1-penten-3-one (P), hexanal (H), *cis*-3-hexenal (C), acetaldehyde (A), β-ionone (B), linalool (L), ethanol (E), furanone (F), 2-phenylethanol (O), and 2 + 3-methylbutanal (M). (A) PCs 1 and 2 (F1 and F 2), and (B) PCs 1 and 3 (F1 and F3).

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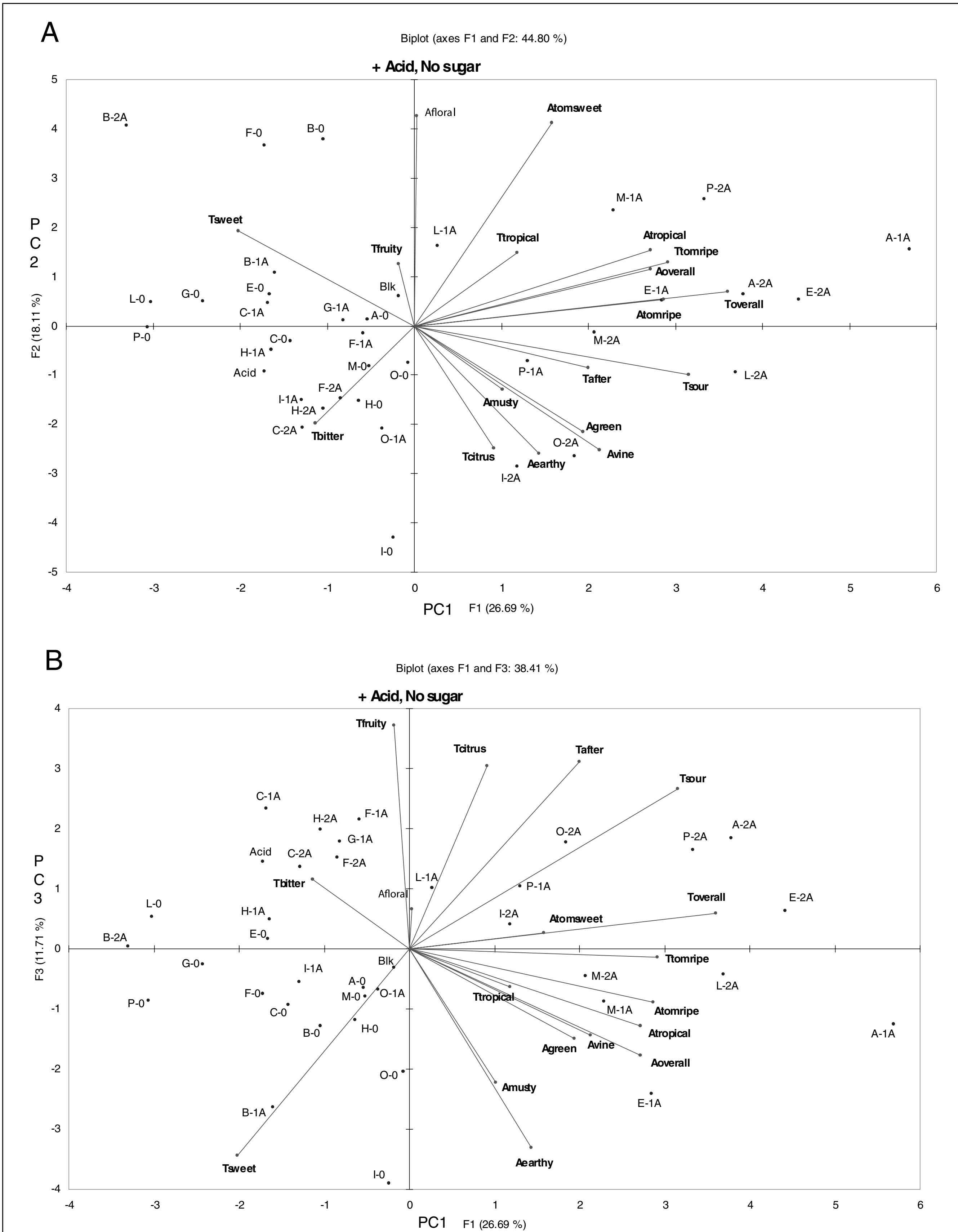

Figure 10 – PCA of taste (T) and aroma (A) descriptors from tomato puree spiked with 0.1% and 0.2% acid solutions in water (1A and 2A, respectively) compared to unspiked puree or blank (Blk) spiked with acid alone (acid), geranylacetone (G), 1-penten-3-one (P), hexanal (H), *cis*-3-hexenal (C), acetaldehyde (A), β-ionone (B), linalool (L), ethanol (E), furanone (F), 2-phenylethanol (O), and 2 + 3-methylbutanal (M). (A) PCs 1 and 2 (F1 and F2), and (B) PCs 1 and 3 (F1 and F3).

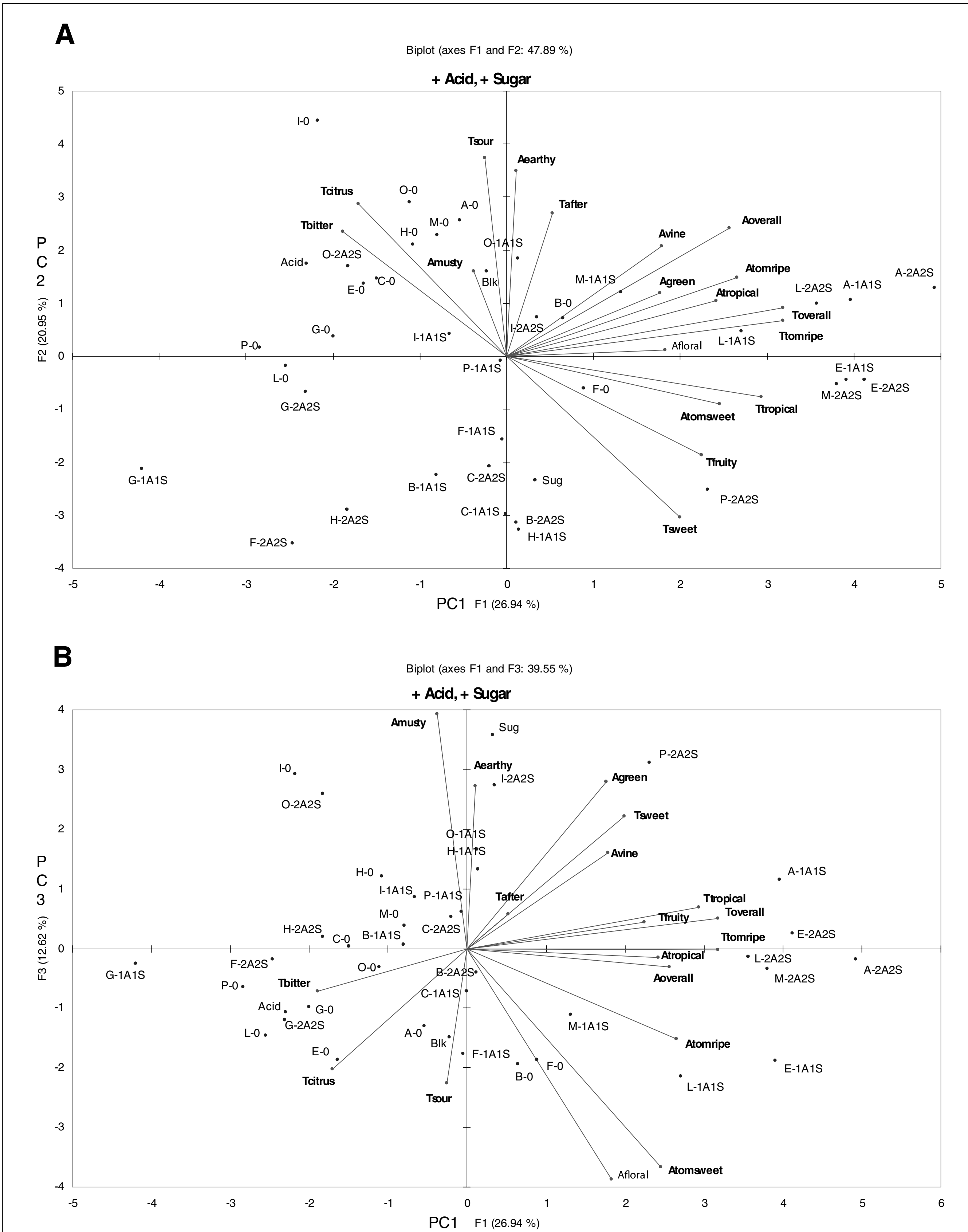

Figure 11 — PCA of taste (T) and aroma (A) descriptors from tomato puree spiked with 1.5% or 3% sugar solutions in water (1S and 2S, respectively) and 0.1% and 0.2% acid solutions in water (1A and 2A, respectively) compared to unspiked puree or blank (Blk) spiked with sugar alone (sug), acid alone (acid), geranylacetone (G), 1-penten-3-one (P), hexanal (H), *cis*-3-hexenal (C), acetaldehyde (A), β-ionone (B), linalool (L), ethanol (E), furanone (F), 2-phenylethanol (O), and 2 + 3-methylbutanal (M). (A) PCs 1 and 2 (F1 and F2), and (B) PCs 1 and 3 (F1 and F3).

aromas and bitter and citrus taste), increased PC2 score for the 1st level of acids (I-1A), and became closer to the green, earthy, and viney aromas for the higher level of added acids (I-2A) (Figure 10A). On the other hand, scores for 2-phenylethanol-spiked samples (O-0, O-1A) became more negative on PC2, and like with 2-isobutylthiazole, samples spiked with 2-phenyethanol with higher level of acids (O-2A) had higher scores for green, earthy, and viney aromas and citrus taste.

The 3rd PC showed a strong effect of added acids on the scores on samples spiked with 2-isobutylthiazole and 2-phenylethanol (Figure 10B). Both samples (I-0, O-0) had very negative scores on PC3 (earthy and musty aromas, and sweet taste), which increased considerably when acid was added. On PC3, it is evident that by adding a higher amount of acids, samples spiked with 2-isobutyltiazole and 2-phenyethanol became less sweet and more sour (O-1A, O-2A, I-1A, I-2A).

PCA for added sugars and acids together

The biplots of PCA vectors for data of spiked puree with both acids and sugars added (Figure 11A and 11B) were very similar to the biplots for data with added sugars (Figure 9A and 9B). The first 2 PCs explained 48% and PC3 (F3) explained an additional 13% of the variance for a total of 61%. Adding sugars and acids to samples spiked with linalool (L-0), ethanol (E-0), acetaldehyde (A-0), and 2 + 3-methylbutanal (M-0) increased scores on PC1 and perception of overall aroma and taste, ripe tomato, and tropical aroma and taste (L-1A1S, L-2A2S, E-1A1S, E-2A2S, A-1A1S, A-2A2S, M-1A1S, M-2A2S), decreasing the perception of citrus and bitter tastes as well as musty aroma (Figure 11A). Samples spiked with 1-penten-3-one had higher scores on fruity and sweet taste (PC2) when sugars and acids were added (P-0, P-1A1S, P-2A2S) (Figure 1B).

Acids and sugars added to samples spiked with hexanal (H-0), *cis*-3-hexenal (C-0), geranylacetone (G-0), and β-ionone (B-0) decreased PC2 scores (H-1A1S, H-2A2S, C-1A1S, C-2A2S, G-1A1S, G-2A2S, B-1A1S, B-2A2S), making them less intense for sour, bitter, and citrus tastes and more intense for sweet and fruity tastes (Figure 10A). Samples spiked with 2-phenylethanol and 2-isobutylthiazole had decreased PC2 scores after addition of acids and sugars, but these scores remained positive. Samples spiked with 2-phenylethanol (O-0) showed increased scores on PC3 when acids and sugars were added (O-1A1S, O-2A2S) moving toward earthy and musty aromas (Figure 11B).

Table 3 — Tomato descriptors generated in previous studies[a] with spiked tomato homogenates or puree.

Tomato puree/ puree spiked with	Descriptor
Geranylacetone	Sweet, citrus, estery
1-Penten-3-one	Fresh, sweet, fruity taste, grassy
Hexanal	Green, grass, mint
cis-3-Hexenal	Viney, green, grass, tomato
2-Isobutylthiazole	Pungent, medicinal
Acetaldehyde	Sweet tomato, musty, tropical, floral
β-Ionone	Floral, sweet
Linalool	Citrusy, fruity, sweet taste
Ethanol	Sweet taste
Furanone	Floral, sweet taste, fruity taste
2-Phenylethanol	Alcohol, nutty
6-Methyl-5-hepten-2-one	Sweet, floral
2 + 3-Methylbutanal	Nutty, stale

[a] Tandon and others (2000, 2001).

Conclusions

Addition of sugars generally weakened sour, citrus, and bitter taste descriptors for (PC2, Figure 9A) as expected. However, they also generally moved descriptors toward overall, ripe tomato, sweet tomato, and tropical aromas as well as overall, tropical, and fruity tastes (PC1, Figure 9A), when added with most volatiles. Addition of acids generally moved descriptors from sweet taste to overall, sour, tropical, ripe tomato, and citrus tastes as well as toward overall, tropical, ripe tomato, and green aromas (PC2, Figure 10A) and from floral and sweet tomato aroma and sweet taste to bitter and citrus tastes as well as earthy, green, viney, and musty aromas (PC1, Figure 10A). Adding sugars and acids together was similar to adding sugars alone except that in addition to increasing perception of ripe and sweet tomato and tropical aromas and tastes, sugars and acids together also added to green, viney, and floral aroma perception (PC1, Figure 11A). Addition of sugars and acids affected partitioning of volatiles added to bland tomato puree into the headspace. The headspace of the tomato puree spiked with 10 μL/L ethanol, linalool, or 6-methyl-5-hepten-2-one resulted in increased or decreased levels of these volatiles as well as acetaldehyde in the case of puree spiked with ethanol (Figure 12) when

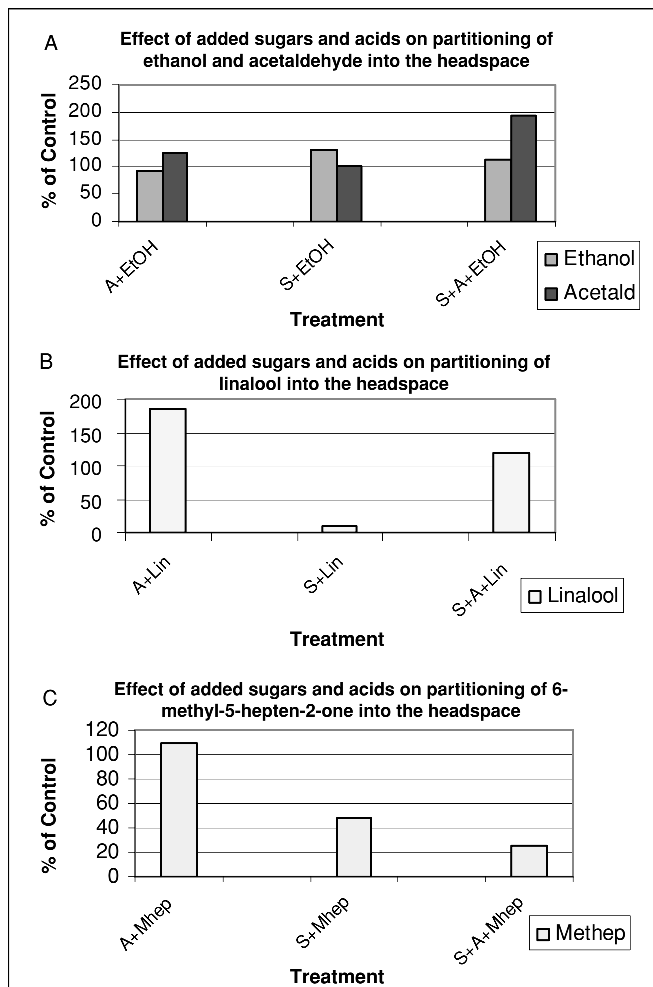

Figure 12 — Levels of spiked volatiles (A) ethanol, (B) linalool and (C) 6-methyl-5-hepten-2-one headspace concentration (samples spiked with ethanol also affected acetaldehyde concentration) expressed as percent of unspiked control. A = added acid, S = added sugar, and S + A = added sugar and acid together; EtOH = ethanol, Lin = linalool and methep or Mhep = 6-methyl-5-hepten-2-one.

sugars and/or acids were added. Levels of naturally occurring volatiles in the puree were also sometimes altered when sugars and/or acids were added (data not shown). Adding green/viney volatiles, like 2-isobutylthiazole and 1-penten-2-one, without extra sugars or acids, enhance viney, green, and earthy aromas and detract from tropical and floral notes. Conversely, adding fruity/floral volatiles like furanone or β-ionone detract from viney, green, and ripe tomato aromas while enhancing sweet tomato, tropical, and floral aromas (Figure 2).

It is evident that adding sugars and acids affects perception of aroma and adding aroma volatiles affects perception of flavor or taste for tomato fruit. Preliminary sensory and chemical studies of tomato breeding lines have shown that enrichment of fruity, floral notes along with de-emphasis of green and musty notes would improve tomato flavor and enhance "sweet" taste without increasing sugars (Baldwin and others 1998; Tandon and others 2003). This study shows that manipulation of volatiles, sugars, and acids can steer tomato flavor in the direction of sweet/ripe tomato, fruity, floral, tropical or toward green, viney, musty, and earthy aromas and tastes.

References

Baldwin EA, Scott JW. 2002. Update on tomato flavor. 2002. Florida Tomato Institute Proceedings, September 4, Naples, Fla., p 7–13.

Baldwin EA, Thompson K. 2000. Effect of sugar type and concentration on perception of tomato sweetness. Proc Florida State Hort Soc 113:287–9.

Baldwin EA, Nisperos-Carriedo MO, Baker R, Scott JW. 1991. Quantitative analysis of flavor parameters in six Florida tomato cultivars (*Lycopersicon esculentum* Mill.). J Agric Food Chem 39:1135–40.

Baldwin EA, Scott JW, Einstein MA, Malundo TMM, Carr BT, Shewfelt RL, Tandon KS. 1998. Relationship between sensory and instrumental analysis for tomato flavor. J Am Soc Hort Sci 123:906–15.

Baldwin EA, Scott JW, Shewmaker CK, Schuch W. 2000. Flavor trivia and tomato aroma: biochemistry and possible mechanisms for control of important aroma components. HortScience 35:1013–22.

Baldwin EA, Goodner K, Plotto A, Pritchett K, Einstein M. 2004. Effect of volatiles and their concentration on perception of tomato descriptors. J Food Sci 69: S310–8.

Brueckner B, Schonhof I, Schroedter R, Kornelson C. 2007. Improved flavor acceptability of cherry tomatoes. Target group: children. Food Qual Pref 18:152–60.

Bruhn CM, Feldman N, Garlitz JH, Ivans E, Marshall M, Riley A, Thurber D, Williamson E. 1991. Consumer perception of quality: apricots, cantaloupes, peaches, pears, strawberries, and tomatoes. J Food Qual 14:187–95.

Buttery RG, Teranishi R, Ling LC. 1987. Fresh tomato aroma volatiles: a quantitative study. J Agric Food Chem 35:540–4.

Civille GV, Lyon BG. 1996. Aroma and flavor lexicon for sensory evaluation. ASTM Publication DS 66. Philadelphia, Pa.: ASTM. p. 158.

King BM, Duineveld CAA, Arents P, Meyners M, Schroff SI, Soekhai ST. 2007. Retronasal odor dependence on tastants in profiling studies of beverages. Food Qual Pref 18:286–95.

Malundo TMM, Shewfelt RL, Scott JW. 1995. Flavor quality of fresh tomato (*Lycopersicon esculentum* Mill.) as affected by sugar and acid levels. Postharvest Biol Technol 6:103–10.

Malundo TMM, Shewfelt RL, Ware GO, Baldwin EA. 2001. Sugars and acids influence flavor properties of mango (*Mangifera indica*). J Am Soc Hort Sci 126:115–21.

March KB, Friel EN, Gunson A, Lund C, MacRae E. 2006. Perception of flavour in standardized fruit pulps with additions of acids or sugars. Food Qual Pref 17:376–86.

Maul E, Sargent SA, Sims CA, Baldwin EA, Balaban MO, Huber DJ. 2000. Tomato flavor and aroma quality as affected by storage temperature. J Food Sci 65:1228–37.

Meilgaard M, Civille GV, Carr BT. 1991. Sensory evaluation techniques. 2nd ed. Boca Raton, Fla.: CRC Press Inc. 354 p.

Neff J. 1996. Tomatoes take on new dimensions. Produce Bus: 22–33.

Petro-Turza M. 1987. Flavor of tomato and tomato products. Food Rev Int 2(3):309–51.

Saltveit ME. 2003. Temperature extremes. In: Bartz JA, Brecht JK, editors. Postharvest physiology and pathology of vegetables. New York: Marcel Dekker Inc. p 457–63.

Tandon KS, Baldwin EA, Shewfelt RL. 2000. Aroma perception of individual volatile compounds in fresh tomatoes (*Lycopersicon esculentum* Mill.) as affected by the medium of evaluation. Postharvest Biol Technol 20:261–8.

Tandon KS, Jordan M, Goodner KL, Baldwin EA. 2001. Characterization of fresh tomato aroma volatiles using GC-olfactometry. Proc Florida State Hort Soc 114:142–4.

Tandon KS, Baldwin EA, Scott JW, Shewfelt RL. 2003. Linking sensory descriptors to volatile and non-volatile components of fresh tomato flavor. J Food Sci 68:2366–71.